Texas A&M Transportation Institute

Concept of Operations and Policy Implications for Unmanned Aircraft Systems Use for Traffic Incident Management (UAS-TIM)

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Concept of Operations and Policy Implications for Unmanned Aircraft Systems Use for Traffic Incident Management (UAS-TIM)

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Executive Summary

Texas freeways experience considerable traffic congestion—some from high traffic volumes and some from traffic incidents, both minor (e.g., crashes, stalls, and road debris) and major (e.g., vehicle rollovers, chemical spills, flooding, and hurricane evacuations). Incidents can literally bring freeways systems to a standstill, which results in significant economic impact for Texas drivers and businesses. Quick response and clearance of traffic incidents through traffic incident management (TIM) practices are proven methods of restoring roadway capacity and increasing mobility on urban freeways.

Transportation agencies and emergency responders are continually seeking new technologies and systems (especially for major incidents) that can improve incident response, monitoring, and clearance. One such system/technology under consideration is unmanned aircraft systems (UAS). Commonly referred to as *drones* in military applications, public and civil UAS could prove to be a flexible and useful tool for transportation agencies and emergency responders.

Concept of Operations

To better understand the policy implications, the Texas A&M Transportation Institute developed a concept of operations (ConOps), an early step in the systems engineering process, with a focus on using UAS as an intelligent transportation systems tool to enhance TIM and provide quick and accurate information from the scene of a traffic incident: UAS-TIM. The ConOps provides a roadmap for the validation of UAS abilities to enhance monitoring, situational awareness, and safety when compared to traditional fixed-location cameras and expensive helicopters.

Regulations

UAS-TIM comes with a number of policy questions. The federal government has recently issued extensive regulations (whose implications are currently beyond the scope of this research effort). Texas state law addresses drones in several areas, including limitations on use of the device and use of the information gathered from the device.

Texas state law is not clear on whether agencies can use UAS-TIM or what limitations the Federal Aviation Administration (FAA) might place on UAS-TIM. For example, while exemptions exist for work on behalf of a law enforcement authority, including when investigating the scene of a human fatality or motor vehicle accident on a state highway, existing language presupposes UAS use only by law enforcement authorities or after a determination of the cause of incident-related congestion.

Researchers expect that agencies will contract with UAS service providers, necessitating clarification of the law's application to service providers. For the validation phase of UAS-TIM, service providers have concerns about the permissions required to park a trailer and have the drone take off from private property adjacent to highway right of way, as well as the collection/retention of private images taken on or adjacent to the right of way incidental to the cause of the incident. These issues are important to UAS service providers because FAA has the authority to revoke their commercial exemptions for UAS operations if they are found in violation of state laws.

Introduction

Texas freeways experience considerable traffic congestion—some from high traffic volumes and some from traffic incidents, both minor (e.g., crashes, stalls, and road debris) and major (e.g., vehicle rollovers, chemical spills, flooding, and hurricane evacuations). Incidents can literally bring freeways systems to a standstill, which results in significant economic impact for Texas drivers and businesses. Quick response and clearance of traffic incidents through traffic incident management (TIM) practices are proven methods of restoring roadway capacity and increasing mobility on urban freeways.

Transportation agencies and emergency responders are continually seeking new technologies and systems (especially for major incidents) that can improve incident response, monitoring, and clearance. One such system/technology under consideration is unmanned aircraft systems (UAS). Commonly referred to as *drones* in military applications, civil UAS could potentially prove to be a flexible and useful tool for transportation agencies and emergency responders.

Statement of Problem

Freeway incidents cause significant congestion and motorist delay, resulting in approximately 25 percent of all non-recurring congestion. This non-recurring congestion greatly reduces capacity and overall system reliability (*1*). Agencies continue to work toward minimizing the impact of non-recurring congestion through various means; the most notable is formal TIM practices.

According to the Federal Highway Administration (FHWA), TIM “consists of a planned and coordinated multidisciplinary process to detect, respond to, and clear traffic incidents so that traffic flow may be restored as safely and quickly as possible” (*2*). The FHWA document *Traffic Incident Management Gap Analysis Primer* (*2*) says that the goals of TIM are to:

- Promote the safety of motorists, crash victims, and incident responders.
- Reduce the time for incident detection and verification.
- Reduce response time (the time for response personnel and equipment to arrive at the scene).
- Exercise proper and safe on-scene management of personnel and equipment, while keeping as many lanes as possible open to traffic.
- Conduct an appropriate response, investigation, and safe clearance of an incident.
- Reduce clearance time (the time required to remove the incident from the roadway).

- Provide timely and accurate information to the public that enables them to make informed choices.
- Get traffic moving again as soon as possible after a partial or complete roadway closure while managing the affected traffic until normal conditions are restored.

As agencies work toward achieving these goals, additional applications and tools are constantly emerging and considered for their feasibility to enhance an agency's ability to manage an incident more effectively and reduce congestion and motorist delay. One such potential emerging incident management tool is UAS, which is an all-encompassing term that includes the aircraft, the ground station and controller, and the communication systems used by the ground station to operate the aircraft.

Project Background

Researchers examined the potential deployment of UAS as a way to improve response, monitoring, and clearance of traffic incidents. Since improved TIM would most likely reduce clearance times and the resulting non-recurring congestion, researchers developed a project vision to facilitate the acceptance and deployment of UAS by transportation agencies. To accomplish this, the project was split into two phases for funding purposes:

- Phase 1: development of a systems engineering document referred to as a Concept of Operations (ConOps) summarized by this report.
- Phase 2: pilot demonstration and validation, which is underway.

To help UAS gain acceptance as a TIM tool, researchers acknowledged that agencies and partnerships such as Houston Transtar would primarily consider UAS an intelligent transportation system (ITS) deployment and require proper systems engineering investigation. Therefore, researchers took the following actions:

- In Phase 1, researchers took an agency-agnostic approach in developing the ConOps.
- In Phase 2, researchers will validate the technology and investigate how recent the Federal Aviation Administration (FAA) rules and regulations and state laws could influence the actions of commercial UAS service providers and operators for transportation purposes. Phase 2 will also provide insight into the potential safety and operational concerns of operating near and over live traffic.

Purpose and Organization of Document

The purpose of this document is to provide a high-level, agency-agnostic, and location-independent ConOps for using UAS as an ITS tool for improved traffic incident management (UAS-TIM). This document assumes that agencies will be able to use the UAS-TIM for real-time incident monitoring, situational awareness, and quick clearance (including fatal crash scene mapping).

A typical ConOps defines the operational mission of a system or group of systems (as a project) and identifies the requirements necessary to achieve that mission. A ConOps should define:

1. The goals, objectives, and capabilities of each system or group of systems.
2. The roles and responsibilities of the implementing agency and affected stakeholders (*3*).

For UAS-TIM and this high-level ConOps, there is no assigned agency or regional area for deployment. Therefore, this document will concentrate on the first purpose, defining the goals, objectives, and capabilities of the UAS-TIM. This document discusses:

- Current uses of UAS in transportation.
- Perceived needs for UAS-TIM.
- The development of ConOps components including goals, functions, key concepts, and operational scenarios.
- Potential UAS-TIM system architecture impacts.
- Potential policy concerns.
- Next steps.

UAS Use in Transportation

Background

Prior to developing a ConOps, researchers had to understand the current status of UAS, their applications to transportation, and, more importantly, state department of transportation (DOT) experience using the technology. Researchers completed an extensive literature review in spring 2016 using Texas A&M University resources. Researchers found that several DOTs have investigated or experimented with using UAS for transportation purposes, mainly for aerial imagery and condition assessment. However, several project reports indicated potential UAS use for traffic monitoring and volume determination.

Examples of DOT Use of UAS

Civil UAS have been gaining momentum for use in transportation because they have become more capable, smaller, and more affordable. UAS uses range from simple video monitoring to pavement crack detection using LIDAR. Not including the current efforts by the Texas Department of Transportation (TxDOT) and the Texas A&M Transportation Institute (TTI), 11 DOTs have investigated or are currently investigating UAS applications or are sponsoring UAS research. Due to the rapid pace at which transportation agencies are investigating UAS for uses in transportation, researchers expect that an update to this section will be necessary and completed during Phase 2 of the project.

Arkansas State Highway and Transportation Department

In 2010, the Arkansas State Highway and Transportation Department research section completed a project investigating mobile systems to monitor traffic from above. The project compared literature about UAS, a mobile mast-mounted camera, and a tethered helium balloon technology for use in collecting high-definition (HD) video and pictures to quantify turning movements, traffic volumes, vehicle headways, queue lengths, and vehicle classification, and to calibrate simulation models. Prior to the testing and demonstration phase of the project, the DOT abandoned UAS as a possible system citing FAA restrictions and time constraints (*4*).

Virginia Department of Transportation

In 2002, the National Consortium on Remote Sensing in Transportation, in cooperation with the Virginia Department of Transportation, demonstrated airborne data acquisition systems for real-time traffic surveillance, monitoring of traffic incidents and signals, and environmental condition assessment of roadside areas (*5*). In August 2014, Virginia Tech announced that its unmanned aircraft test site was fully operational. UAS demonstrations were carried out on the DOT's Smart Road, a 2.2-mile section of limited-access roadway used for testing new technologies (*6*).

Florida Department of Transportation

Over a span of four years, the University of Florida completed an airborne traffic monitoring proof-of-concept study for the Florida Department of Transportation. The University of Florida selected the Aerosonde make of UAS after engaging over 50 UAS vendors. This project also focused heavily on communication and obtained the necessary equipment to outfit two microwave towers. Unfortunately, FAA denied approval of a certificate of authorization (COA) for this project. The specific points of contention were the "see and avoid"[1] and safe landing issues. Due to these concerns and the denial of the COA, the DOT canceled the project, citing no solution to the "see and avoid" and safe landing issues (*7*).

Ohio Department of Transportation

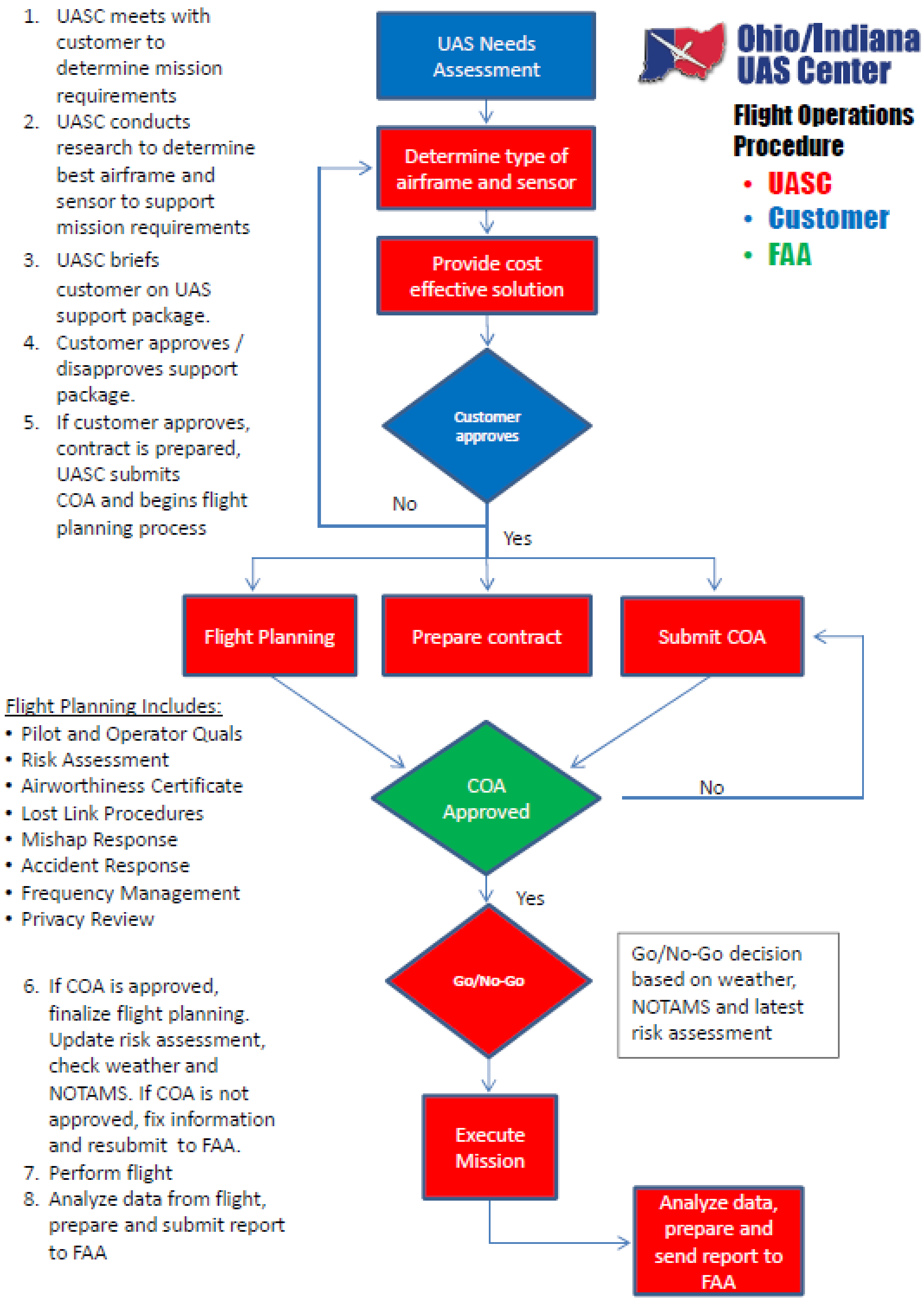
In 2002, Ohio State University performed field experiments in Columbus to determine the feasibility of collecting data on freeway conditions, intersection movements, network paths, and parking lots (*8*). Described as an innovator in 2013, the Ohio Department of Transportation continued the process of implementing UAS for more efficient and effective operations. However, the DOT noted that the biggest challenge was obtaining clearance to fly in the national airspace. Working closely with FAA, the DOT has developed a method to streamline the COA process (*9*).

In 2013, the governor of Ohio, John R. Kasich, announced a joint initiative with Indiana to develop an unmanned aircraft systems center to advance the commercialization of the technology and support UAS research. The center is formally a component of the Ohio Department of Transportation; the Ohio Legislature passed a declaration supporting the center. The current website offers services including flight operations (Figure 1) and flight testing (Figure 2), including language about pay-based services (*10*).

Washington Department of Transportation

In 2008, the Washington Department of Transportation, in collaboration with the University of Washington's Washington State Transportation Center, completed two test flights of specific UAS: the MLB BAT and the Yamaha R-Max (Figure 3). The primary purpose of testing UAS was to determine the feasibility of using UAS technology to control avalanches and capture images including traffic conditions (*11*).

[1] UAS cannot sense and avoid or see and avoid beyond the line of sight and direct control of a ground operator and spotter. FAA currently does not allow for use beyond line of sight without an exemption.



Source: (*10*)

Figure 1. Ohio/Indiana UAS Center Flight Operation Procedures.

Source: (*10*)

Figure 2. Ohio/Indiana UAS Center Test Flight Steps and Processes.

Source: (*11*)

Figure 3. The Yamaha R-Max.

Utah Department of Transportation

Utah State University and the Utah Water Research Lab completed an evaluation of UAS for the Utah Department of Transportation in 2012. The primary objectives of the project were to use UAS to capture high-resolution images of construction projects for monitoring and to classify wetland plant species. Utah State University conducted several flights. Researchers captured images before, during, and after completion of the Southern Parkway Highway at the Utah Airport and the Utah Lake Wetlands. The results of the project were favorable, and researchers concluded that UAS as a tool had value for digital imagery including roadway traffic conditions and for wetland monitoring and mitigation permitting (*12*).

Georgia Department of Transportation

In 2014, the Georgia Institute of Technology completed a feasibility study for the Georgia Department of Transportation, studying the potential of UAS application for DOT operations. Researchers developed basic goals and information requirements, and proposed five reference systems for the ability to capture real-time data including:

- Flying camera.
- Flying total station.
- Perching camera.
- Medium altitude long endurance.
- Complex manipulation.

In addition to developing reference systems, the researchers interviewed 24 Georgia Department of Transportation staff members and concluded that the primary areas of application were collecting data, providing information, and making decisions based on the data. The report also listed future research needs in the areas of economics and intangible benefits (*13*).

California Department of Transportation

In August 2014, the California Department of Transportation produced a report on the use of UAS for steep terrain investigation. Initial work focused on previous DOT experiences, the role of FAA, UAS applications, and training resources. The report discusses prior California Department of Transportation research for using UAS for bridge inspection in 2008 but indicates that the DOT had not completed any additional UAS research. The report indicates future research in the areas of proof-of-concept testing and close monitoring of the FAA regulatory environment (*14*).

Michigan Department of Transportation

The Michigan Department of Transportation evaluated five UAS platforms with a combination of various payloads including optical, thermal, and LIDAR sensors. The DOT directed the evaluation at UAS capabilities to assess critical transportation infrastructure such as bridges, confined spaces, traffic flow, and roadway assets (*15*).

North Carolina Department of Transportation

In August 2013, the State of North Carolina approved a test UAS program at North Carolina State University. In March 2014, the DOT presented a report on unmanned aircraft use to the North Carolina Legislative Joint Oversight Committee on Information Technology, the Joint Legislative Transportation Oversight Committee, and the Fiscal Research Division. The report was in response to the legislative request that included coordination with the chief information officer and aviation division director of the DOT to develop a proposal for the implementation of a UAS program. The program listed several areas that would benefit from UAS use including agriculture, surveying, wildlife monitoring, state infrastructure monitoring, migration monitoring, and emergency management. A breakdown of the cost of the UAS program was also provided, estimating a startup cost of $850,000 and recurring annual costs of $435,250 (*16*).

West Virginia Division of Highways

In 2012, West Virginia University researchers successfully demonstrated that UAS can be a low-cost solution to providing a stable aerial platform for transportation use. The project, funded jointly by the Mid-Atlantic Universities Transportation Center and the West Virginia Division of Highways, used a fixed-wing aircraft to capture aerial images and develop geo-referencing software (*17*).

Other Documented Transportation Applications

Incident Management and Crash Mapping

The department of research and development at the Norwegian Air Ambulance Foundation examined using a remotely piloted aircraft system for major incidents and emergency response. Researchers tested the system under five extreme cases including a mass casualty traffic accident, mountain rescue, avalanche with buried victims, fisherman through thin ice, and search for casualties in the dark. Researchers found that remotely piloted aircraft can be effective despite payload and other limitations for supporting situation assessment, making decisions, and exchanging information (*18*).

Crash Mapping

A study in China developed a UAS-based mapping system to get crash data quickly from a scene. Researchers deployed a quadcopter to understand the necessary specifications such as payload, cost, and flight altitude. The system is capable of extracting precise maps of an incident, and researchers considered the system very useful for complex accidents where multiple vehicles are involved. Additional safety benefits were determined for facilities with high travel speed and those incident where agencies might consider it unsafe to investigate the crash scene in person. The system uses a camera and image-processing software, and researchers suggest the system could be useful for traffic accident investigations (*19*).

High-Definition Imagery for Traffic Flow Management

A feasibility study by the University of Arizona in cooperation with Ohio State University investigated the quality of data that operators could receive from a rotary UAS. The project was successful in showing that UAS could capture HD imagery and track vehicles. Researchers conducted a two-minute flight, classified vehicles, and determined their direction. Researchers also estimated parameters such as velocity and tracked distance before developing statistical error (*20*).

Airborne Road Traffic Monitoring with Radar

This project used synthetic aperture radar and ground moving-target indication to estimate traffic flow with radar using a high-altitude UAS (*21*).

Real-Time Road Detection

The University of California–Berkeley presented a real-time road detection algorithm. The proposed algorithm can detect roadways in real time by using a snapshot of the target roadway. The concept is to use UAS technology to capture video, detect road boundaries, and define the roadway structure. Researchers determined that for this concept to be feasible, the UAS would have to fly low enough to capture road pavement markings (*22*).

Statistical Profile Generation from Traffic Monitoring Using Real-Time UAS-Based Video Data

The eye in the sky project from the University of South Florida proposes the use of small rotary UAS for collecting real-time data. Agencies can use the data for monitoring traffic in real time, evaluating traffic patterns, and gathering accurate traffic counts. Researchers attached custom-made vision systems to the vehicle (including pan and tilt cameras) for dynamic tracking and car following. Researchers collected video data and calculated traffic occupancy, capacity, and density. Researchers then fed these parameters into a traffic model to develop future traffic conditions (*23*).

Vehicle Detection from Aerial Imagery

Using a rotary-wing UAS, this project focused on the methods to detect vehicles automatically in two distinct stages:

- The first stage used an algorithm looking for man-made objects by feature, density, clustering, and color.
- The second stage used a target classification to reduce false alarms (*24*).

Real-Time Video Relay for UAS Traffic Surveillance Systems through Available Communications Networks

A Western Michigan University project focused on methods to relay real-time video for traffic surveillance purposes. The problem was in relaying the video data to the Michigan Department of Transportation. The streaming video data were too large for available network bandwidths and as a result had to be compressed using a Windows encoder (*25*).

Roadway Traffic Monitoring from a UAS

The University of Ohio investigated the use of UAS (BAT III) for the purpose of developing traffic parameters such as level of service, annual average daily traffic, intersection operations, traffic flow, and parking. Researchers used two methods of estimating roadway densities: using still frames and using a series of frames. Researchers also used a geographical information system to develop roadway lengths and calculate traffic volumes (*26*).

Perceived Needs for UAS-TIM

In 2010, FHWA published a document containing information about best practices in TIM (*27*) and listed five functional areas of TIM that face challenges:

- Detection and verification.
- Traveler information.
- Response.
- Scene management and traffic control.
- Quick clearance and recovery.

Within these functional areas, FHWA listed challenges. UAS-TIM could act as a strategy for the following areas:

- Inaccurate incident reports.
- Difficulty of on-scene maneuverability.
- Responder safety.
- Secondary incidents.
- Excess delay.
- Lengthy minor-incident clearance.
- Lengthy major-incident clearance.

Researchers developed three needs for UAS-TIM based on the findings of the 2010 best practices report:

- Need 1: incident monitoring (incident command participation).
- Need 2: situational awareness.
- Need 3: quick clearance and recovery.

Need 1: Incident Monitoring (Incident Command Participation)

Coordinating the responding resources at the scene of an incident requires clear communication and feedback from the scene. Agencies traditionally monitor incidents from cameras at fixed locations. Having the flexibility to monitor incidents from multiple angles and directly overhead would provide a better overall understanding of the scene to the command center.

The majority of agency static pan, tilt, and zoom cameras are at a height of less than 100 feet. A typical UAS has an operating ceiling of 400 feet. This upper operating limit would provide for significant visual advantage for the monitored corridor and adjacent and intersecting corridors (Figure 4).

Figure 4. SH 6 at US 290—Pan, Tilt, and Zoom versus 400-Foot Elevation View.

This need addresses the following challenges:

- Inaccurate incident reports.
- Difficulty of on-scene maneuverability.
- Responder safety.

Need 2: Situational Awareness

Traffic management efforts are often limited to primary incidents being handled by the first responders and the local traffic management center (TMC). At times, there may also be:

- Secondary incidents (caused by congestion or queues resulting from the primary incident).
- Rerouting of traffic from the primary incident location.
- The development of significant queuing from both reduced capacity and rubbernecking.

This need addresses the following challenges:

- Difficulty of on-scene maneuverability.
- Responder safety.
- Secondary incidents.
- Excess delay.

Secondary Crash Monitoring

Ideally, incident managing agencies would like to be able to not only monitor the primary incident but also observe, report, and respond to secondary incidents.

Multiple Route Monitoring (Previously Unmonitored)

Prior to significant rerouting/diversion of traffic, agencies would like to be able to check that a diversion route is feasible (especially a route of significant distance and/or drop-in functional classification—for example, from an access-controlled freeway to an urban multilane highway). Checking the diversion route would examine any existing closures due to construction, other traffic incidents, and events along the diversion route. Monitoring would also provide the opportunity to coordinate with local agencies to prepare for an increase in traffic through their jurisdiction.

Traffic Queue Monitoring

Often significant queuing occurs as a result of the primary incident. Ideally, the management of the primary incident would also include the ability to predict, observe, and confirm the development of queues as a result of the incident. Existing established systems include significant data collection and the use of algorithms to predict the end of queues. However, if agencies could obtain real-time information by placing a cursor that moves with the end of the queue, agencies could use this real-time queuing information for decision making and alternate routing.

Need 3: Quick Clearance and Recovery

The longer an incident remains on the freeway system, the longer the queues, higher the delays, and higher the chances for secondary crashes. The concept of quick clearance involves the reduction in the time to detect, confirm, and clear an incident. Recovery includes monitoring the incident scene and investigating fatal crashes.

This need addresses the following challenges:

- Excess delay.
- Lengthy minor incident clearance.
- Lengthy major incident clearance.

Incident Detection and Confirmation

Agencies identify and confirm all incidents manually with the assistance of fixed cameras, and use automated warnings for significant drops in speeds. Additional incident detection technology and flexibility can greatly reduce the time necessary to identify and confirm incidents. This is especially true for traffic incidents near difficult terrain or as a result of natural events.

Monitoring of Incident Scene

Issues related to the ability to clear an incident, including roadside conditions, bodies of water, and large grade differentials, can increase delays, especially if unknown by responders. Additional flexibility to survey roadside conditions may positively impact clearance times.

Fatal Crash Investigation

Fatal crashes and the corresponding investigation can cause significant delays including full roadway closures. A certification of death by a medical examiner is usually required before bodies are moved and the scene can be cleared. Additionally, documentation of the scene is required, and the quicker investigators can complete this documentation, the sooner emergency officials can clear the scene.

Researchers believe that service providers can attach sensor technologies as a payload to the UAS to provide three-dimensional imaging and—in combination with HD photogrammetry—provide a record of the crash scene.

Concept of Operations

UAS-TIM is a deployable tool that provides safe and enhanced monitoring capability and payload flexibility for a variety of potential applications including traffic monitoring and crash-scene mapping and photogrammetry. Agencies can use these UAS capabilities to meet the TIM needs of situational awareness, incident monitoring (incident command participation), and quick clearance.

UAS-TIM Goals

Agencies can deploy TIM-UAS to meet a variety of potential operational and TIM objectives. States would most likely deploy UAS-TIM to:

- Reduce non-recurring congestion by reducing incident clearance times.
- Improve incident responder safety by providing enhanced images and video to the incident command center.
- Improve incident responder safety by removing staff members from unsafe incidents such as chemical spills and incidents involving bodies of water and large grade differentials.
- Improve real-time incident monitoring capabilities through capturing video and images at higher elevations (within FAA regulations), using a mobile platform and innovative sensor payloads (e.g., infrared).
- Improve real-time monitoring capabilities of resulting queues, alternative routes, and secondary crashes due to incidents through capturing video and images at higher elevations (within FAA regulations) and using a mobile platform.
- Reduce fatal crash clearance times by reducing the amount of time needed to map and document crash scenes.

Components

Many components are required to support UAS-TIM functionality. The minimum requirements include:

- **UAS**—the vehicle or system that carries imaging and sensor payloads that will be flying near or over live traffic. The UAS is assumed to have onboard navigational equipment.
- **Digital imaging payload**—the HD camera attached to the UAS.
- **Various sensor payloads**—infrared, LIDAR, etc.
- **UAS-TIM response unit**—a vehicle (probably a truck) to respond and deploy a UAS (Figure 5).

- **UAS-TIM ground station**—a navigational computer and control station for the UAS.
- **Communications infrastructure**—equipment that allows the UAS-TIM ground station to transmit real-time data to a TMC.
- **Two-way communications**—equipment that allows the UAS-TIM ground station crew to communicate with TMC staff.

Source: (*28*)

Figure 5. Example UAS Response Unit.

Capabilities and Functions of UAS-TIM

While researchers can develop minimum specifications for UAS-TIM deployment, agencies will have to determine mission requirements in order to customize a UAS to meet their specific functional needs. Researchers have assumed that specifications and capabilities are inherent to the UAS and corresponding ground station; however, users need to meet minimum conceptual requirements to accomplish UAS-TIM.

UAS-TIM Capabilities

Researchers expect that agencies would only deploy UAS-TIM for high-priority traffic incidents involving fatalities, chemical spills, or a lengthy expected clearance time. The UAS needs to be able to operate over water and under certain weather conditions (e.g., high winds or extreme heat) according to the specifications of the UAS manufacturer and the expectations of the deploying agency for its intended purpose (e.g., flooding or hurricane evacuation). The UAS will also need to be able to operate over agency-owned and private property as needed. The assumed capabilities of UAS-TIM are as follows.

Real-Time Enhanced Video and Photography

The UAS should be able to capture and deliver HD video and photography from within the airspace and elevations as allowed by FAA regulations and approximately 400 feet above the grade of the lowest agency-owned facility near a traffic incident. The UAS should be able to effectively communicate with a central command center as needed.

Real-Time Non-video Sensor Data

The UAS should be able to capture sensor data (e.g., infrared for heat signature, motion, and electronic signals) from within the airspace and elevations as approved by FAA regulations. The UAS should be able to effectively communicate with a central command center and deliver sensor data as needed.

Real-Time Payload (Cameras and Sensors) Mobility

The UAS should be mobile and have the ability to collect video, photography, and sensor data while moving within the airspace and elevations as approved by FAA regulations. The UAS should be able to effectively communicate with a central command center and deliver video, photography, and sensor data as needed.

Communication of Data to a Traffic Incident Command Center

The UAS should be able to effectively communicate with a central command center and deliver video, photography, and sensor data as needed. The UAS should use secure information channels, and researchers expect it to first communicate with a ground station and then effectively communicate in real time from the ground station to a central command.

Guided Mobile Data Collection

The UAS should be able to be guided by a pre-programmed flight plan (for global positioning system and elevation waypoints) and collect video, photography, and sensor data while moving within the airspace and elevations as approved by FAA regulations.

Photogrammetry and Mapping

The UAS should be able to provide accurate navigational data and photography as required to meet the agency minimum requirements needed for legal proceedings resulting from a fatal crash.

Safe Flight Operation near or over Live Traffic

The UAS should be able to operate safely near and over live traffic within the airspace and elevations as approved by FAA regulations.

UAS-TIM Functions

Agencies can customize and deploy UAS-TIM to support a wide variety of incident management functions. At a minimum, UAS-TIM must support the following functionality.

Real-Time Confirmation of a Traffic Incident

UAS-TIM should provide the information necessary to confirm the severity and extent of a traffic incident.

Real-Time Monitoring of a Traffic Incident

UAS-TIM should provide enhanced real-time video, photography, and sensor data monitoring functionality (to existing static cameras).

Real-Time Monitoring of Alternate Routes

UAS-TIM should provide real-time video, photography, and sensor data of alternate routes that agencies can use for traffic diversion decision making.

Real-Time Monitoring of Traffic Incident Queuing

UAS-TIM should provide real-time video, photography, and sensor data of traffic queuing as a result of the traffic incident.

Real-Time Monitoring of Secondary Crashes

UAS-TIM should provide real-time video, photography, and sensor data of secondary crashes and incidents to aid in response.

Fatal Crash Scene Mapping

UAS-TIM should quickly provide sensor data (e.g., photogrammetry and LIDAR) that exceeds the capabilities of manual crash scene mapping, with the aim to reduce the clearance time of the incident.

Expanded UAS-TIM Functionality

During a meeting with potential implementers, researchers discovered that UAS-TIM could also serve in an expanded capacity. UAS-TIM could provide video that agencies can use for incident management training purposes.

Operational Scenarios

Researchers created five operational scenarios that explore possible operational responses to incidents. TTI developed the scenarios in response to the determined TIM needs and variation of incident response possibilities. The scenarios become useful to aid in planning and determining the expected payloads of UAS.

Operational Scenario 1: Incident Monitoring

Agencies could use the incident monitoring scenario to monitor incidents where cameras are not readily available or do not have the ability to pan, tilt, or zoom. Agencies could also use this scenario simply for the added mobility of the camera for monitoring purposes. Figure 6 illustrates a potential layout of a basic UAS-TIM incident monitoring operational scenario.

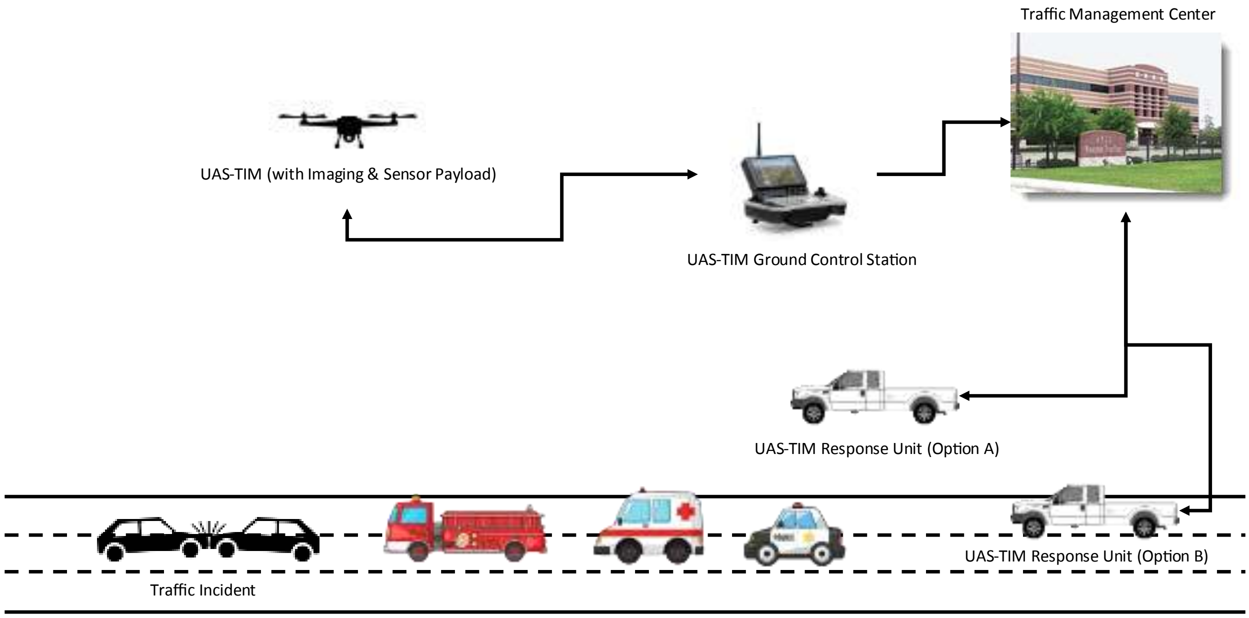


Figure 6. Operational Scenario 1: Incident Monitoring.

The steps involved in this operational scenario include:

1. The TMC receives traffic incident information.
2. Based on agency UAS-TIM deployment protocols (type, extent, severity, etc.), the TMC/command center deploys a UAS-TIM response unit to the scene.
3. The UAS-TIM response unit arrives at the traffic incident scene and positions itself on a frontage road or private parking lot (Option A) or positions itself behind first responders (Option B).
4. The UAS-TIM response unit launches a UAS with digital imaging payload.
5. The UAS-TIM digital imaging payload communicates with the UAS-TIM ground station, transmitting real-time HD video.
6. The UAS-TIM ground station transmits HD video to the TMC.
7. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and/or UAS position. If possible, the ground station may give camera control to the TMC, but UAS control always remains with the UAS-TIM ground station.
8. Depending on the battery life (for untethered UAS) of the UAS-TIM, operators bring the UAS back to the UAS-TIM response unit for battery exchange and relaunch. The response unit may consider multiple UAS for improved transition.
9. The UAS-TIM follows responder protocols before departing from the traffic incident scene primarily based on instructions from the TMC.

Operational Scenario 2: Situational Awareness

Agencies could use the situational awareness scenario to better understand how nearby facilities are operating and being effected by an original incident. With accurate situational information, agencies will be able to make better decisions concerning traffic diversions and the need for additional response. Figure 7 illustrates a potential layout of a basic UAS-TIM situational awareness operational scenario.

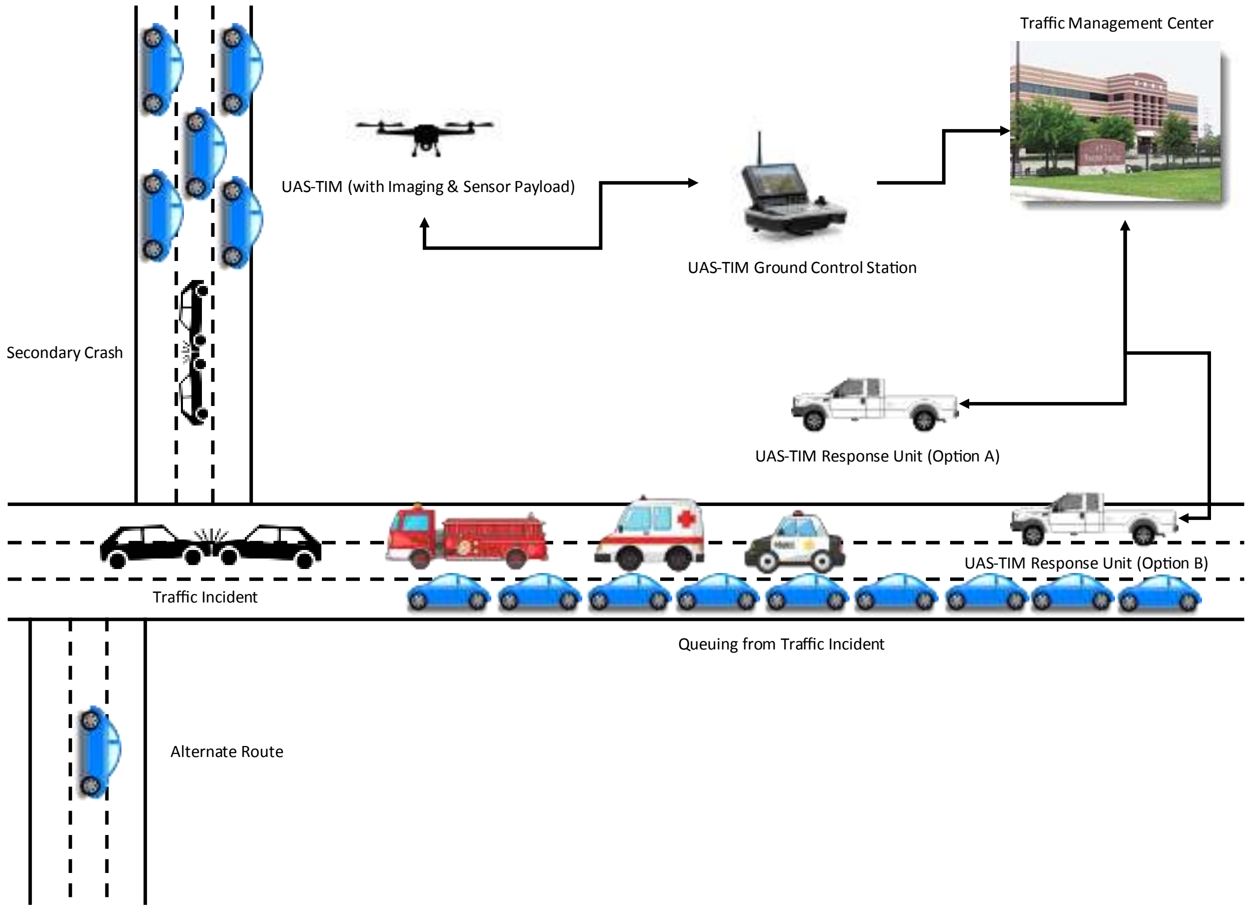


Figure 7. Operational Scenario 2: Situational Awareness.

The steps involved in this operational scenario include:

1. The TMC receives traffic incident information.
2. Based on agency UAS-TIM deployment protocols (type, extent, severity, etc.), the TMC/command center deploys a UAS-TIM response unit to the scene.
3. The UAS-TIM response unit arrives at the traffic incident scene and positions itself on a frontage road or private parking lot (Option A) or positions itself behind first responders (Option B).
4. The UAS-TIM response unit launches a UAS with digital imaging payload.

5. The UAS-TIM digital imaging payload communicates with the UAS-TIM ground station, transmitting real-time HD video.
6. The UAS-TIM ground station transmits HD video to the TMC.
7. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and/or UAS position. If possible, the ground station may give camera control to the TMC, but UAS control always remains with the UAS-TIM ground station.
8. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and/or UAS position to monitor secondary crashes, queuing, and alternative routes.
9. Depending on the battery life (for untethered UAS) of the UAS-TIM, operators bring the UAS back to the UAS-TIM response unit for battery exchange and relaunch. The response unit may consider multiple UAS for improved transition.
10. The UAS-TIM follows responder protocols before departing from the traffic incident scene primarily based on instructions from the TMC.

Operational Scenario 3: Difficult Terrain, Safety, or Maneuverability

Agencies could use the difficult terrain, safety, or maneuverability scenario when an incident takes place near areas of hazards or difficult terrain. Figure 8 illustrates a potential layout of a UAS-TIM response for an incident with difficult terrain, safety concerns, or maneuverability issues.

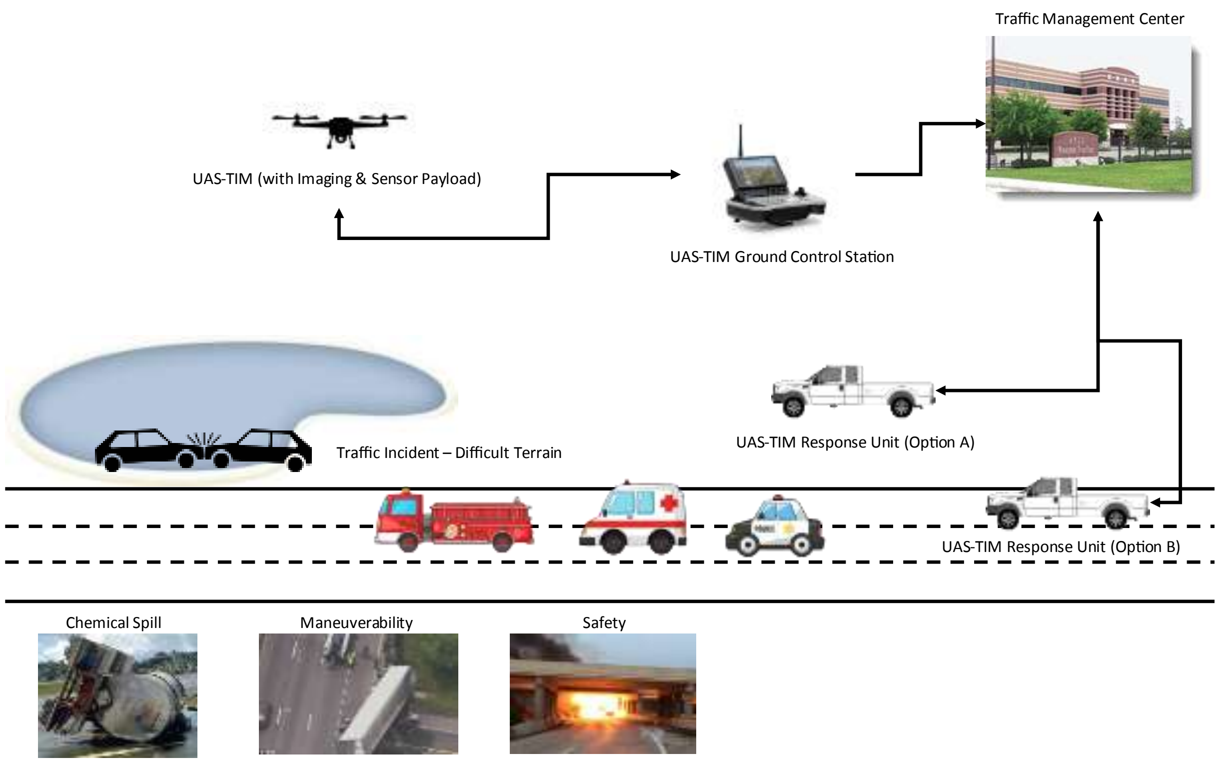


Figure 8. Operational Scenario 3: Difficult Terrain, Safety, or Maneuverability.

The steps involved in this operational scenario include:

1. The TMC receives traffic incident information.
2. Based on agency UAS-TIM deployment protocols (type, extent, severity, etc.), the TMC/command center deploys a UAS-TIM response unit to the scene.
3. The UAS-TIM response unit arrives at the traffic incident scene and positions itself on a frontage road or private parking lot (Option A) or positions itself behind first responders (Option B).
4. The UAS-TIM response unit launches a UAS with digital imaging payload.
5. The UAS-TIM digital imaging payload communicates with the UAS-TIM ground station, transmitting real-time HD video.
6. The UAS-TIM ground station transmits HD video to the TMC.
7. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and UAS position. If possible, the ground station may give camera control to the TMC, but UAS control always remains with the UAS-TIM ground station.
8. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and UAS position to investigate, confirm, and monitor an incident taking

place in or on difficult terrain (e.g., bodies of water, steep grades, or elevation changes), to address safety concerns (e.g., chemical spills), or to improve maneuverability.

9. Depending on the battery life (for untethered UAS) of the UAS-TIM, operators bring the UAS back to the UAS-TIM response unit for battery exchange and relaunch. The response unit may consider multiple UAS for improved transition.

10. The UAS-TIM follows responder protocols before departing from the traffic incident scene primarily based on instructions from the TMC.

Operational Scenario 4: Natural Event

Agencies could use the natural event scenario during flooding and natural disasters such as after a hurricane. Figure 9 illustrates a potential layout of a UAS-TIM response to an incident occurring from a natural event.

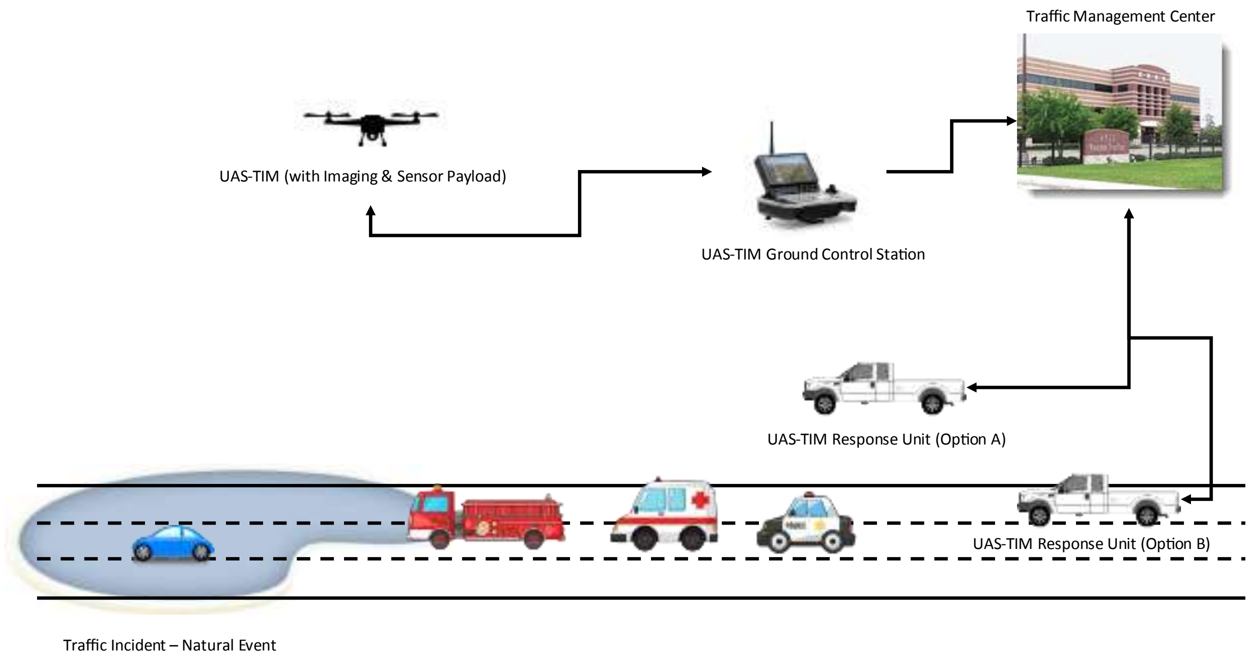


Figure 9. Operational Scenario 4: Natural Event.

The steps involved in this operational scenario include:

1. The TMC receives traffic incident information.

2. Based on agency UAS-TIM deployment protocols (type, extent, severity, etc.), the TMC/command center deploys a UAS-TIM response unit to the scene.

3. The UAS-TIM response unit arrives at the traffic incident scene and positions itself on a frontage road or private parking lot (Option A) or positions itself behind first responders (Option B).

4. The UAS-TIM response unit launches a UAS with digital imaging payload.

5. The UAS-TIM digital imaging payload communicates with the UAS-TIM ground station, transmitting real-time HD video.
6. The UAS-TIM ground station transmits HD video to the TMC.
7. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and UAS position. If possible, the ground station may give camera control to the TMC, but UAS control always remains with the UAS-TIM ground station.
8. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and UAS position to investigate, confirm, and monitor incidents taking place during natural events such as flooding.
9. Depending on the battery life (for untethered UAS) of the UAS-TIM, operators bring the UAS back to the UAS-TIM response unit for battery exchange and relaunch. The response unit may consider multiple UAS for improved transition.
10. The UAS-TIM follows responder protocols before departing from the traffic incident scene primarily based on instructions from the TMC.

Operational Scenario 5: Fatal Crash Scene Mapping

Agencies could use the fatal crash scene mapping scenario to help expedite the required documentation of a fatal accident. Figure 10 illustrates a potential layout of the UAS-TIM operational scenario involving crash scene mapping after a fatal crash.

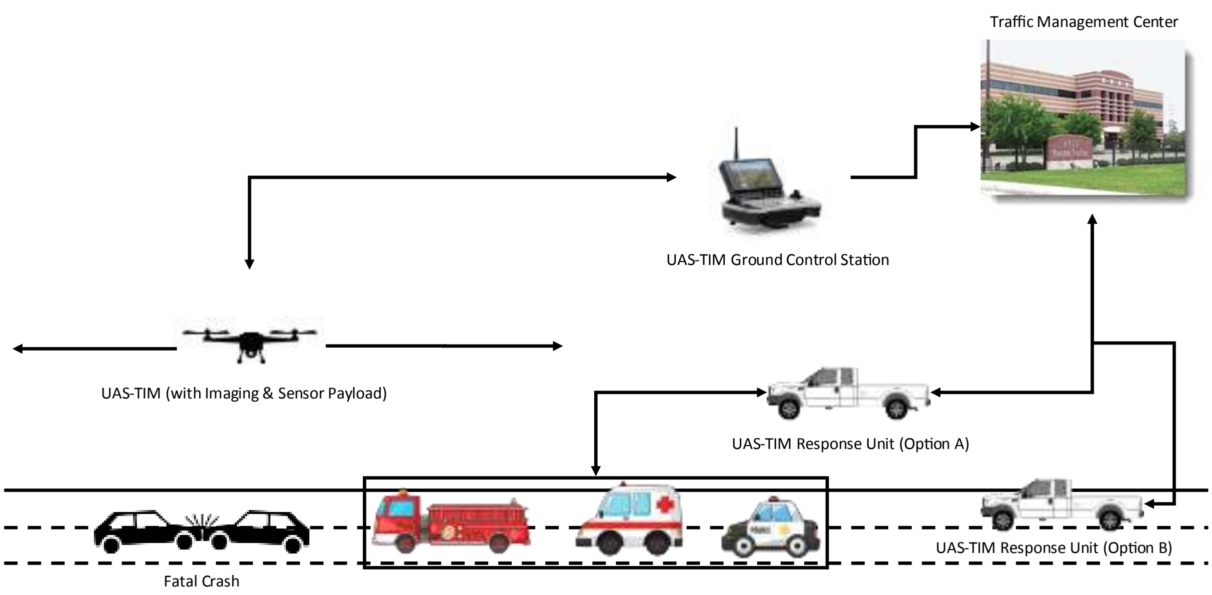


Figure 10. Operational Scenario 5: Fatal Crash Scene Mapping.

The steps involved in this operational scenario include:

1. The TMC receives traffic incident information.
2. Based on agency UAS-TIM deployment protocols (type, extent, severity, etc.), the TMC/command center deploys a UAS-TIM response unit to the scene.
3. The UAS-TIM response unit arrives at the traffic incident scene and positions itself on a frontage road or private parking lot (Option A) or positions itself behind first responders (Option B).
4. The UAS-TIM response unit launches a UAS with digital imaging payload.
5. The UAS-TIM digital imaging payload communicates with the UAS-TIM ground station, transmitting real-time HD video.
6. The UAS-TIM ground station transmits HD video to the TMC.
7. The UAS-TIM ground station crew communicates with TMC staff to adjust video (pan, tilt, and zoom) and/or UAS position. If possible, the ground station may give camera control to the TMC, but UAS control always remains with the UAS-TIM ground station.
8. Depending on the battery life (for untethered UAS) of the UAS-TIM, operators bring the UAS back to the UAS-TIM response unit for battery exchange and relaunch. The response unit may consider multiple UAS for improved transition.
9. Steps 4–8 are repeated when Operational Scenario 5: Fatal Crash Scene Mapping follows Operational Scenario 1: Incident Monitoring.
10. Upon receiving instruction from the TMC or first responders, the UAS-TIM adjusts payload according to the desire mapping capabilities required by the local jurisdiction (e.g., three-dimensional photogrammetry or LIDAR) and makes multiple passes along the crash scene for mapping purposes.
11. The UAS-TIM ground control station downloads and verifies data capture and follows responder protocols before departing from the traffic incident scene.

Architecture

Because UAS-TIM would be an ITS deployment, researchers verified that UAS would fit within the existing national ITS architecture. Figure 11 provides an overview of the service package graphic for the ATMS08 Traffic Incident Management System. This figure shows the interactions between different physical entities (as described in the architecture). "Other Traffic Management" provides and receives data about road network conditions, traffic images, and incident information.

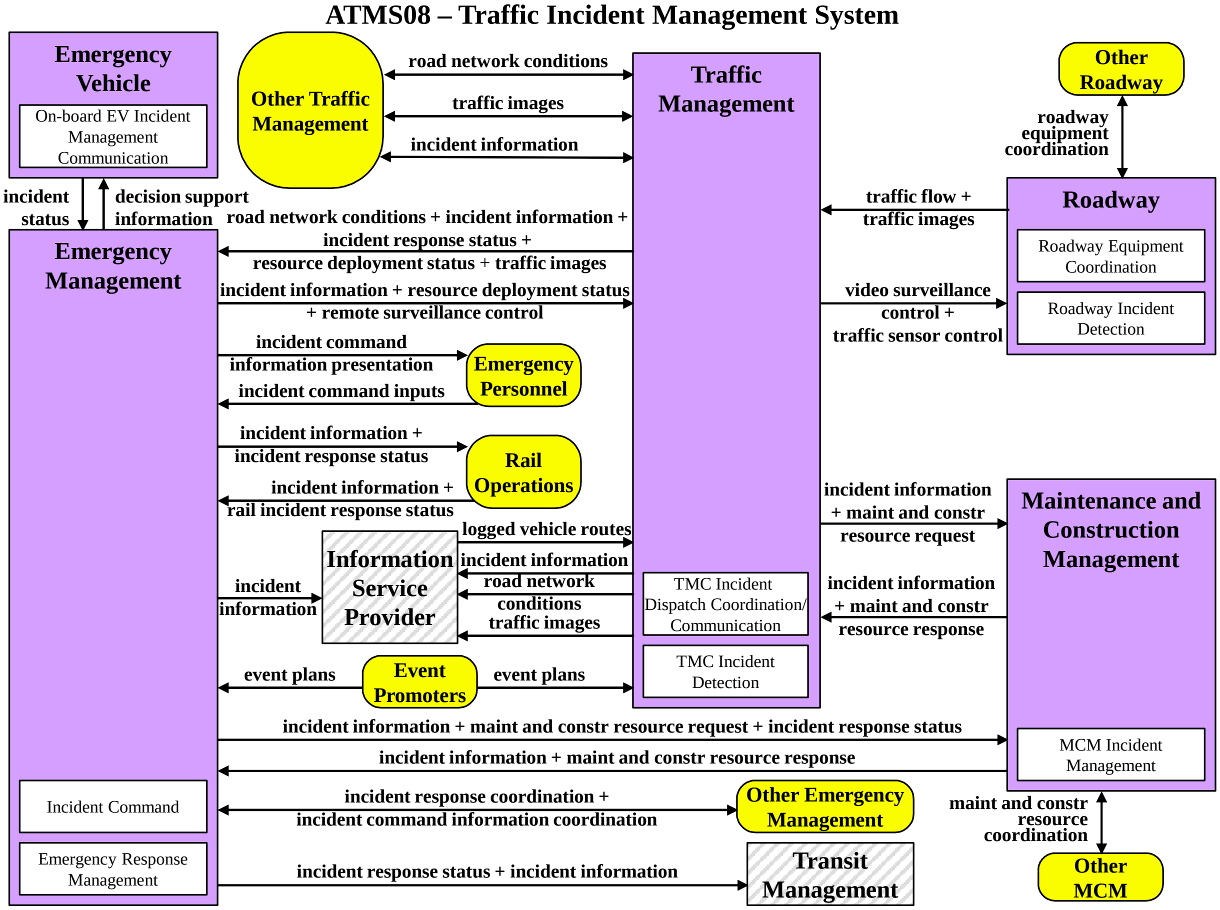


Figure 11. National ITS Service Package Graphic for TIM Systems.

Researchers expect that UAS-TIM would find a home in the "Other Traffic Management" area (see Figure 12).

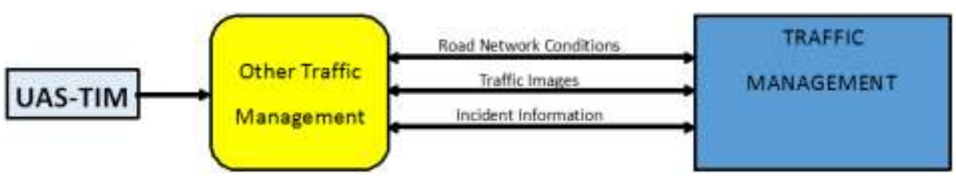


Figure 12. UAS-TIM Architecture.

Policy Considerations

Many regulations and policy considerations concern UAS-TIM. Most notable are the ever-changing FAA rules and regulations. In addition to these federal rules, states have legislation concerning when and where UAS can be flown and for what purposes. Policy also differs depending on what type of organization is flying the UAS (e.g., test center, public agency, or private company). On September 1, 2016, FAA published and made effective a new set of rules and regulations (14 CFR Part 107). Researchers have only briefly reviewed these new policies at the time of this report. However, researchers have added a separate task in Phase 2 for a comprehensive review of 14 CFR Part 107. Additionally, in concern for public safety, regulations can address operational safety considerations so that public agencies can understand and identify who is best prepared to fly UAS safely and effectively.

FAA Rules and Regulations

FAA rules and regulations concerning UAS are constantly changing. Separate rules also apply to public aircraft and civil (private) aircraft. FAA regulations address the process by which a UAS can be safely operated in FAA airspace including operations, registration, maintenance, inspection, visual line of sight, proximity to airports, and emergencies. As an exercise in preparation for Phase 2, the Lone Star UAS Center of Excellence and Innovation provided flight restriction maps for major urban centers in Texas, which are included as the Appendix.

Public Aircraft

FAA Advisory Circular 00-1.1A, *Public Aircraft Operations*, primarily governed FAA regulations for public aircraft prior to the release of 14 CFR Part 107. With the release of Part 107, public agencies (law enforcement, public universities, state governments, and local governments) can operate UAS under two conditions, according to FAA (*29*):

1. Fly under the small UAS rule—follow all rules under 14 CFR part 107, including aircraft and pilot requirements. The Aircraft must be used for civil purposes.
   OR
2. Obtain a Certificate of Waiver or Authorization (COA)—permits nationwide flights in Class G airspace at or below 400 feet, or at a specific location and altitude, self-certification of the UAS pilot, and the option to obtain emergency, jurisdictional or special government interest COAs under special circumstances.

Civil (Private) Aircraft

Previously governed by Section 333 Exemptions of the Modernizations and Reform Act of 2012, civil UAS operators were required to apply and received a Section 333 exemption for commercial (e.g., real estate or surveying) operations. FAA published Advisory Circular 107-2 on June 21 and replaced Section 333 effective September 1, 2016. The new rules and regulations also created a remote pilot certification program, which is required to operate UAS in FAA airspace.

Texas Laws and Legislation

Various state laws have bearing on UAS operations in Texas.

Texas House Bill 912

The following excerpts from House Bill (HB) 912 apply to UAS operations (*30*):

> AN ACT relating to images captured by unmanned aircraft and other images and recordings; providing penalties.
>
> SECTION 1. This Act shall be known as the Texas Privacy Act.
>
> Sec. 423.001. DEFINITION. In this chapter, "image" means any capturing of sound waves, thermal, infrared, ultraviolet, visible light, or other electromagnetic waves, odor, or other conditions existing on or about real property in this state or an individual located on that property.
>
> Sec. 423.002. NONAPPLICABILITY. (a) It is lawful to capture an image using an unmanned aircraft in this state:
>
> (1) for purposes of professional or scholarly research and development by a person acting on behalf of an institution of higher education, as defined by Section 61.003, Education Code, including a person who:
>
> (A) is a professor, employee, or student of the institution; or
>
> (B) is under contract with or otherwise acting under the direction or on behalf of the institution;
>
> (2) in airspace designated as a test site or range authorized by the Federal Aviation Administration for the purpose of integrating unmanned aircraft systems into the national airspace;
>
> (8) if the image is captured by a law enforcement authority or a person who is under contract with or otherwise acting under the direction or on behalf of a law enforcement authority:
>
> (C) for the purpose of investigating the scene of:
>
> (i) a human fatality;
>
> (ii) a motor vehicle accident causing death or serious bodily injury to a person; or
>
> (iii) any motor vehicle accident on a state highway or federal interstate or highway;

(D) in connection with the search for a missing person;

(E) for the purpose of conducting a high-risk tactical operation that poses a threat to human life; or

(F) of private property that is generally open to the public where the property owner consents to law enforcement public safety responsibilities;

(9) if the image is captured by state or local law enforcement authorities, or a person who is under contract with or otherwise acting under the direction or on behalf of state authorities, for the purpose of:

(A) surveying the scene of a catastrophe or other damage to determine whether a state of emergency should be declared;

(B) preserving public safety, protecting property, or surveying damage or contamination during a lawfully declared state of emergency; or

(C) conducting routine air quality sampling and monitoring, as provided by state or local law;

(10) at the scene of a spill, or a suspected spill, of hazardous materials;

(11) for the purpose of fire suppression;

(12) for the purpose of rescuing a person whose life or well-being is in imminent danger;

Sec. 423.003. OFFENSE: ILLEGAL USE OF UNMANNED AIRCRAFT TO CAPTURE IMAGE. (a) A person commits an offense if the person uses an unmanned aircraft to capture an image of an individual or privately owned real property in this state with the intent to conduct surveillance on the individual or property captured in the image.

Texas House Bill 1481

The following excerpt from HB 1481 prohibits the operation of an unmanned aircraft over certain facilities, creating a criminal offense (*31*):

Sec. 423.0045. OFFENSE: OPERATION OF UNMANNED AIRCRAFT OVER CRITICAL INFRASTRUCTURE FACILITY.

This section does not apply to conduct described by Subsection (b) that is committed by:

(1) the federal government, the state, or a governmental entity;

(2) a person under contract with or otherwise acting under the direction or on behalf of the federal government, the state, or a governmental entity;

(3) a law enforcement agency;

(4) a person under contract with or otherwise acting under the direction or on behalf of a law enforcement agency;

(5) an owner or operator of the critical infrastructure facility;

(6) a person under contract with or otherwise acting under the direction or on behalf of an owner or operator of the critical infrastructure facility;

(7) a person who has the prior written consent of the owner or operator of the critical infrastructure facility;

(8) the owner or occupant of the property on which the critical infrastructure facility is located or a person who has the prior written consent of the owner or occupant of that property; or

(9) an operator of an unmanned aircraft that is being used for a commercial purpose, if the operator is authorized by the Federal Aviation Administration to conduct operations over that airspace.

Texas House Bill 2167

HB 2167 relates to certain images captured by an unmanned aircraft. This bill amends HB 912 passed in the previous session by adding the following three additional items to the "Nonapplicability" section (*32*):

> a registered professional land surveyor in connection with the practice of surveying…provided no individual is identifiable in the image
>
> a licensed professional engineer…in connection with the practice of engineering…provided no individual is identifiable in the image
>
> a person acting on behalf of an institution of higher education or a private or independent institution of higher education

Potential State Regulations for UAS Operations

With the development of FAA's remote pilot certification program, potential UAS operators must meet educational and testing requirements for civil UAS operation. Currently, FAA limits UAS operation over people unless granted an exemption. When considering operating over live traffic and/or the general public, it may be appropriate to consider additional third-party vetting for operators to demonstrate to FAA that service providers can conduct these types of missions safely and effectively.

One such program already exists in a partnership between the Texas A&M Engineering Extension Service and the Lone Star UAS Center of Excellence and Innovation, a State of Texas FAA UAS Test Site. These agencies have developed one of the first national UAS credentialing programs. This program offers Section 333 exemption/CFR 14 Part 107 service providers the opportunity to receive a third-party vetting, oral audit, and live-flight operational audit of all of their operational and safety policies, procedures, and qualifications required by FAA. The credentialing program offers multiple tracks including state and federal disaster response and energy-sector activities. Researchers are not fully knowledgeable about the direct impact this credentialing program has on the safety and effectiveness of UAS operations but will briefly investigate the potential benefits in Phase 2 of the project.

Operating UAS over Private Property

When organizing the operational scenarios portion of this document, researchers used the insights of a Houston-based Section 333 Exemption UAS service provider to determine appropriate operational response scenarios. During these discussions, the service provider was very cautious concerning the state laws requiring property owner permission to fly UAS. Their primary concern was losing their nationwide exemption due to violation of state laws. The intent of state laws concerning UAS needs to be supplemented and/or clarified.

This was also evident during a previous TxDOT-sponsored research project focused on access management where the commercial UAS service provider requested a letter from TxDOT granting it permission to fly over state right of way. The service provider made these requests despite language in HB 912 concerning nonapplicability for scholarly research on behalf of a law enforcement authority and/or for investigating the scene of a human fatality or motor vehicle accident on a state highway.

In discussion for Phase 2 of this project, where researchers will potentially use service providers to complete pilot demonstration missions, the same service provider has already indicated it would again request a letter of permission to fly over public agency property. The service provider was also not comfortable flying over private property adjacent to public right of way, potentially limiting the usefulness of the application.

Findings and Next Steps

Findings

This research demonstrates that agencies could use UAS-TIM as an effective tool to help with recurring congestion from traffic incidents. Researchers found significant research questions about operating UAS over live traffic and people—even more so under real-time TIM conditions.

Next Steps

To continue to learn about the capabilities and limitations of UAS-TIM, live demonstrations of both the UAS and real-time communications are necessary to evaluate and determine the effectiveness of the system and its potential to reduce congestion.

Evaluation Protocol

For a live demonstration, researchers must first establish a data collection and performance measurement plan to compare typical incident management practices to demonstrations using UAS-TIM. Understanding performance measures will allow researchers to evaluate and validate UAS. Observations and discussions with responders and TMC staff will also provide insight into the benefit of UAS-TIM.

Agency Participation

Researchers will coordinate with participating public agencies. Currently, the Metropolitan Transit Authority of Harris County has verbally committed to the demonstration phase of the project. Researchers are also working with the City of Corpus Christi and are beginning to coordinate with the TxDOT Aviation Division to explore opportunities to demonstrate UAS over/near TxDOT right of way. Advanced digital imaging technology may not necessarily require the UAS to operate over public right of way at all. Some digital imaging payload and stabilization technologies can allow for enhanced imaging miles away.

FAA Authorization and Safe Operation

Researchers must investigate the process of gaining authorization from FAA to fly over live traffic and people and must better understand airspace restrictions. Additionally, the emerging concept of additional vetting and credentialing needs to be studied to determine when and if they are necessary for safe and effective UAS operation. Discussion with Texas A&M Engineering Extension Service leadership revealed that the release of 14 CFR Part 107 may quickly increase the number of commercial UAS service providers, primarily due to the relaxation of the rules related to the qualifications of UAS pilots and not having to secure COAs.

In this first demonstration of UAS-TIM in Texas, agencies and researchers need to be confident that operators have legal authorization to fly and can do so safely. TTI will require service providers to meet every FAA regulation and legal requirement during flight missions. TTI will only consider using service providers that have a safe operating record and credentials that recognize safe and effective operation ability, such as from the National UAS Credentialing Program. This vetting process brings a higher level of safety and standards to those individual companies that public agencies may consider.

Selection of UAS Service Providers

TTI is considering different service providers to partner with, including using the tethered UAS service provider that the National Operations Center of Excellence recently highlighted in a nationwide webinar. Researchers expect that in addition to a private commercially exempt service provider, TTI will explore partnering with the Lone Star UAS Center of Excellence and Innovation, an FAA UAS Test Site. It is unknown what FAA will require for a commercial service provider to fly over live traffic.

Partnering with an FAA UAS Test Site will allow greater flexibility if FAA restrictions prevent successful civil UAS missions. The Lone Star UAS Center of Excellence and Innovation has direct communications with FAA and has the authority to operate in the national airspace at higher altitudes and under different conditions (e.g., nighttime missions) compared to Part 107 commercial service providers. Additionally, the use of an FAA UAS Test Site provides for a greater safety management system than potentially a commercial service provider would possess and provides mission feedback to FAA. However, the project still aims to investigate important policy issues surrounding public and civil UAS operations.

Policy and Legal Impacts

There is a need to better understand the various Texas laws and federal regulations with respect to the legality of UAS-TIM. This is especially true with state UAS property laws and the newly implemented 14 CFR Part 107.

Continuing Research

The next phase of continuing research will include the following activities:

1. Develop a data collection plan.
2. Select and contract with a UAS service provider and/or FAA Test Site.
3. Complete a comprehensive review of 14 CFR Part 107.
4. Complete a legal review of HB 912 and HB 1481.
5. Conduct a UAS-TIM demonstration (over live traffic).
6. Evaluate the demonstration and prepare a formal report.

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Appendix—Texas Urban Airspace Analyses

Figure 13. Austin Airspace Analysis.

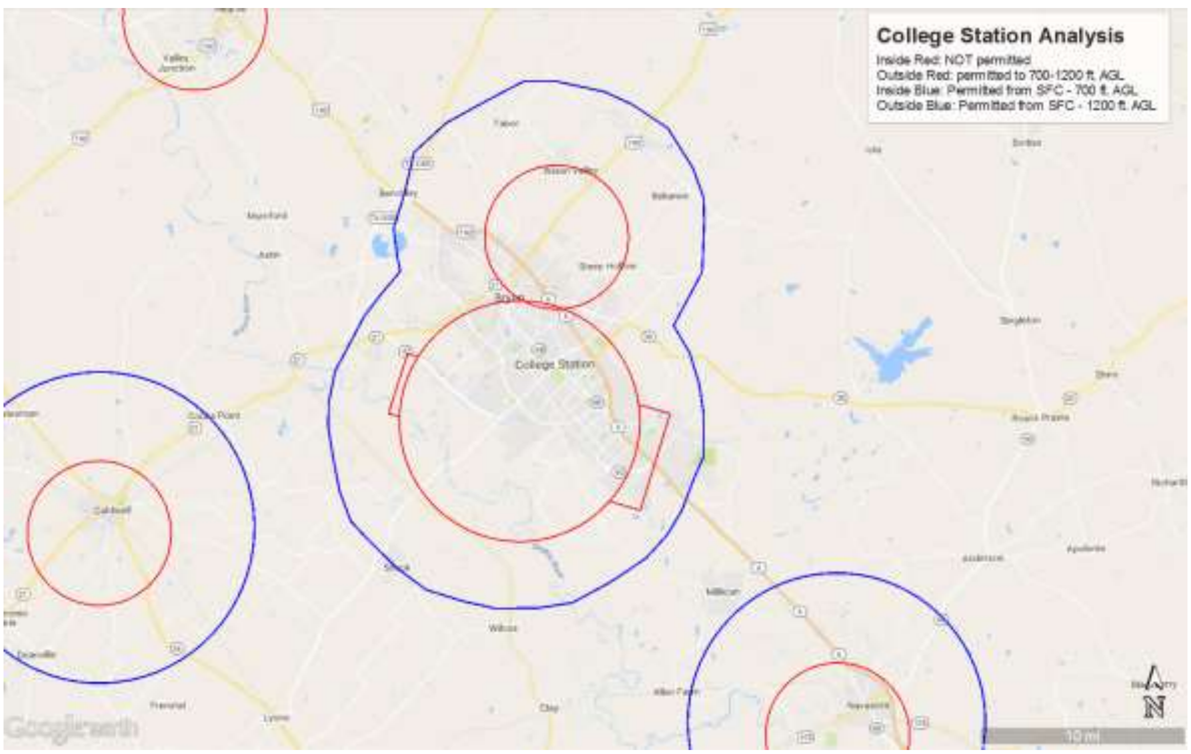

Figure 14. College Station Airspace Analysis.

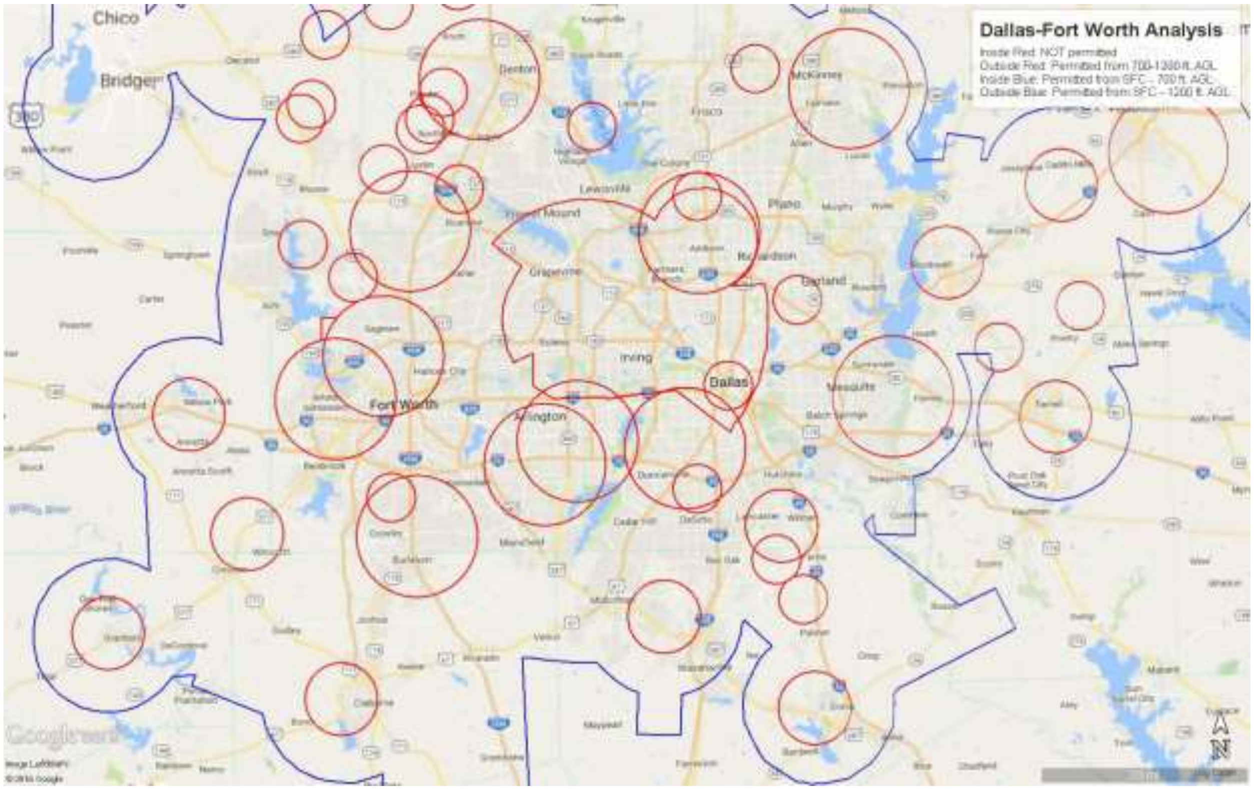

Figure 15. Dallas-Fort Worth Airspace Analysis.

Figure 16. El Paso Airspace Analysis.

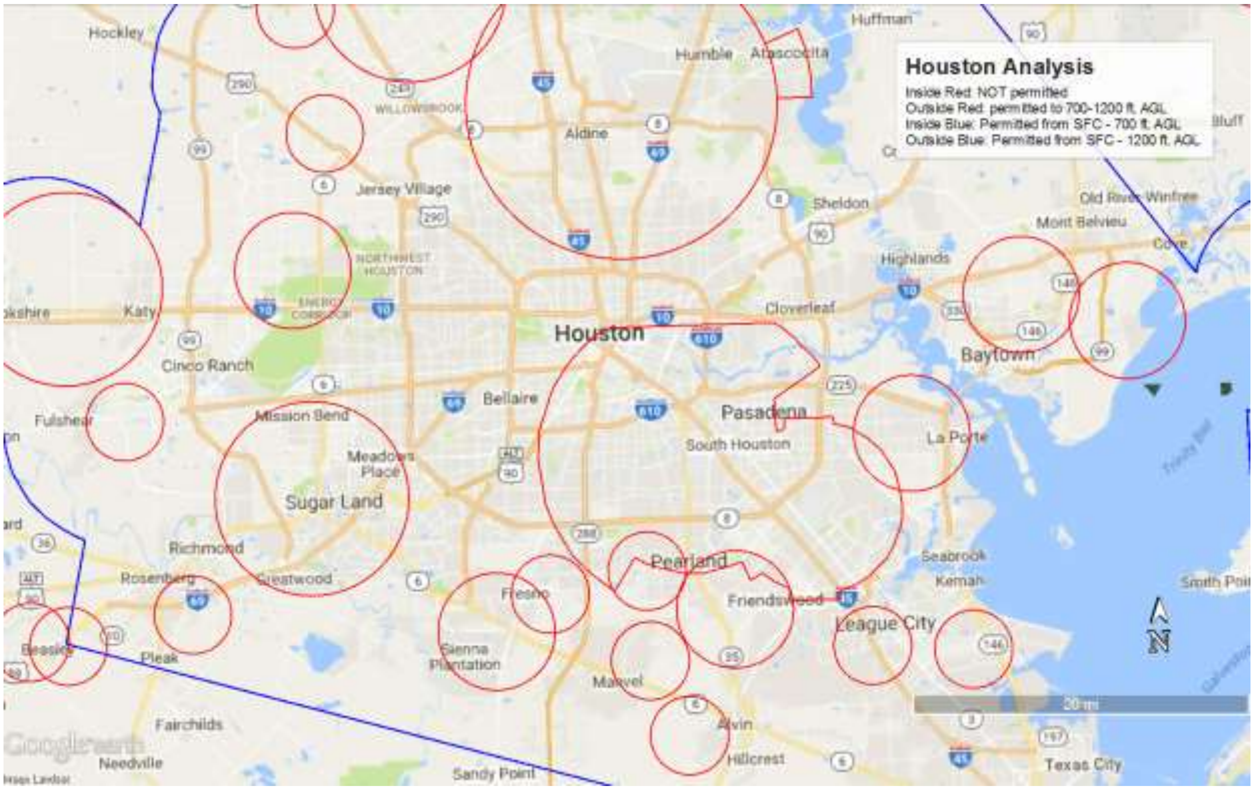

Figure 17. Houston Airspace Analysis.

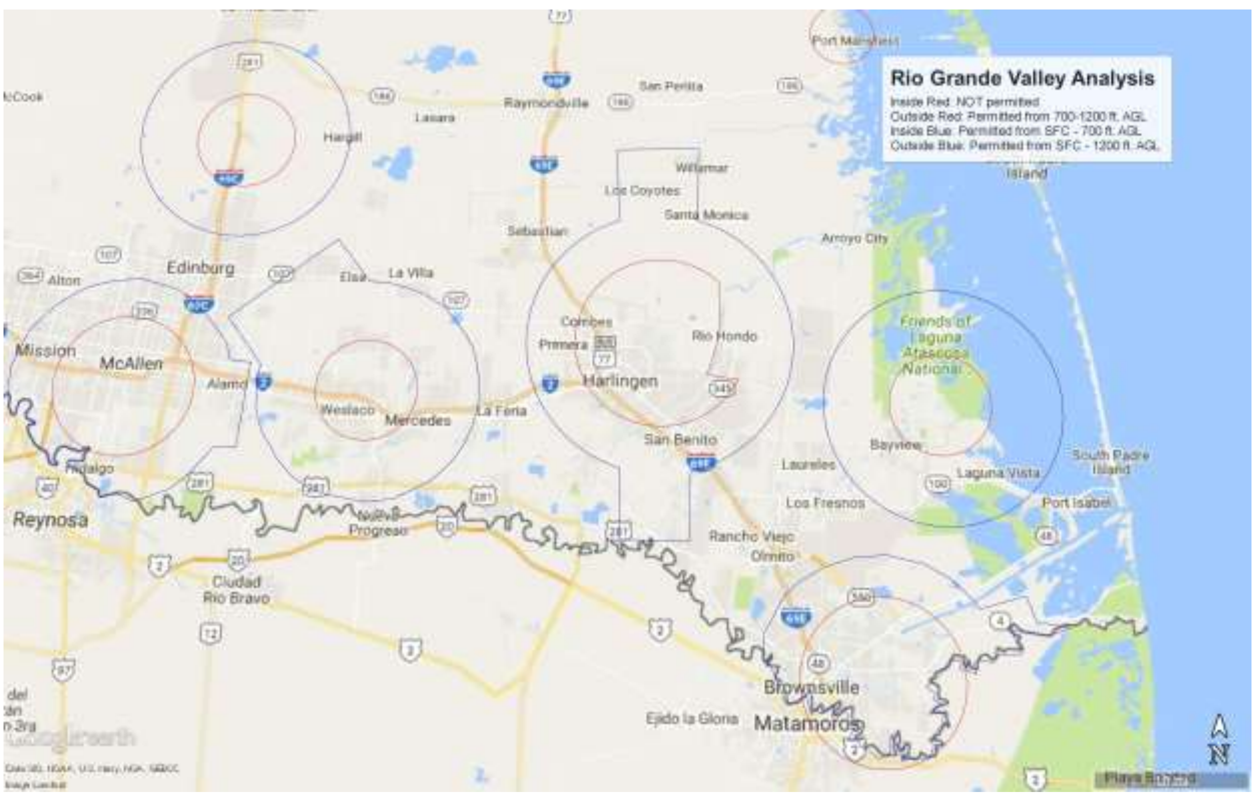

Figure 18. Rio Grande Valley Airspace Analysis.

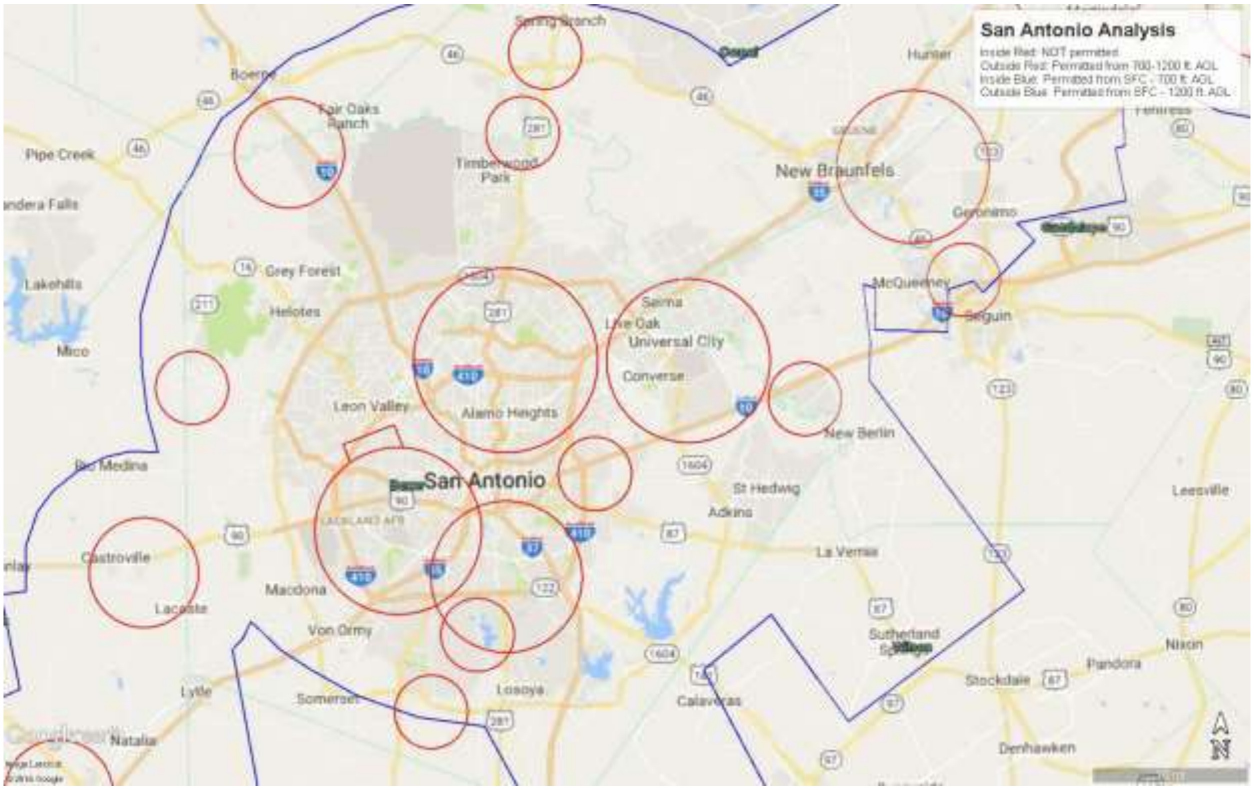

Figure 19. San Antonio Airspace Analysis.